



Astrobiology: The Case for Venus

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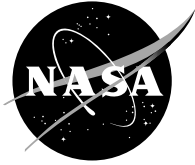
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1. Why Astrobiology?

The scientific discipline of astrobiology addresses one of the most fundamental unanswered questions of science: are we alone? Is there life elsewhere in the universe, or is life unique to Earth?

The field of astrobiology includes the study of the chemical precursors for life in the solar system; it also includes the search for both presently existing life and fossil signs of previously existing life elsewhere in our own solar system, as well as the search for life outside the solar system. Two of the promising environments being currently considered within the solar system are the surface of the planet Mars, and the hypothesized oceans underneath the ice covering the moon Europa. Both of these environments differ in several key ways from the environments where life is found on Earth; the Mars environment in most places too cold and at too low pressure for liquid water to be stable, and the sub-ice environment of Europa lacking an abundance of free energy in the form of sunlight.

The only place in the solar system where we know that life exists today is the Earth. To look for life elsewhere in the solar system, one promising search strategy would be to find and study the environment in the solar system with conditions that are most similar to the environmental conditions where life thrives on the Earth. Specifically, we would like to study a location in the solar system with atmospheric pressure near one bar; temperature in the range where water is liquid, 0 to 100 C; abundant solar energy; and with the primary materials required for life, carbon, oxygen, nitrogen, and hydrogen, present. Other than the surface of the Earth, the only other place where these conditions exist is the atmosphere of Venus, at an altitude of about fifty to sixty kilometers above the surface [1-4].

2. Venus

2.1 The Suitability of the Venus Environment for Life

In the early solar system, about four billion years before present, the sun was approximately twenty-five percent less luminous than it is today. Under these conditions, it is plausible to suggest that Venus was much more Earthlike than it is today. As the solar luminosity increased, Venus became trapped in a runaway “moist greenhouse effect.” [3] The rising temperature increased the evaporation of water vapor from the oceans; this increased water vapor in the atmosphere increased the trapping of infrared radiation, which increased the heating of the planet. Eventually this feedback loop resulted in the oceans boiling dry (and hence releasing very large amounts of greenhouse gas into the atmosphere), and shortly thereafter any surface carbonate rocks decomposed into the primary minerals plus carbon dioxide, releasing their carbon dioxide back into the atmosphere. The thick carbon dioxide atmosphere and intense

greenhouse effect results in the high atmospheric pressure (about 90 bar) and high temperature (approximately 450C) found on the surface of Venus now.

However, above the cloud layers, the atmosphere of Venus is remarkably earthlike (although lacking free oxygen). As shown in figure 1, the atmospheric pressure is one bar, equal to the pressure of Earth's surface, at an altitude of about fifty kilometers above the surface. At the altitude where the pressure is about one bar, the temperature is about 350 K; decreasing to 263 K at an altitude of 60 km above the surface.

While the surface is perpetually cloud covered (figure 2), at approximately the one bar level, considerable sunlight is available. The atmospheric composition is primarily carbon dioxide and nitrogen; the cloud aerosol particles are primarily sulfuric acid (H_2SO_4) droplets. The elements required for life, then, carbon, oxygen, nitrogen, and hydrogen, are all present.

2.2 Scientific Questions in the Study of Venus

Venus is an interesting subject for scientific study.

The planet Venus has a number of fundamental scientific mysteries, both in its atmosphere, and on its surface. Crisp et al. [5] calls the environment of Venus "among the most enigmatic in the solar system." He notes that, although the volatile inventory of Venus is not yet fully characterized, existing measurements suggest that the relative abundances of the noble gases in its atmosphere are much more solar-like than those on the other two terrestrial planets. Similarly, although today Venus has an inventory of water that is a hundred thousand times less water than that of Earth, the deuterium to hydrogen ratio in the atmosphere is on the order of 150 larger for Venus than for Earth. Since hydrogen is more easily lost from the atmosphere than deuterium, this suggests that the original amount of water present on Venus may have been comparable or larger than that on Earth. The detailed process and timing of this large loss of water are not known, leaving a large blank area in efforts to understand the history and change of the surface and atmosphere. Likewise, the cycle of sulfur in the Venus atmosphere is not yet understood. The sulfur interacts with the surface minerals, which serve as a repository of sulfur. Are there presently active sources of atmospheric sulfur, in the form of volcanoes or gas vents?

The details of the atmospheric dynamics of Venus are also not yet understood. Although the surface of Venus rotates very slowly, with a 242 day period, the atmosphere at the cloud level and higher moves around the planet a period of 4 days, 60 times faster than the surface. The question of exactly what mechanism supports this atmospheric super-rotation is a question that has eluded detailed explanation since its discovery by spacecraft in the early 1970s.

The surface of Venus is also of great scientific interest. What has caused the geologically recent resurfacing of the planet? Venus lacks large tracts of young and old crust, a signature of Earth's plate tectonics, and lacks evident plate boundary features. The mountaintops of Venus have some indication of interesting mineralogy that is different from that of the lower altitudes. The nature of this mineralogy is unknown.

The most exciting discovery remaining to be made in the solar system would be the discovery of life outside of Earth. As a near twin of Earth, Venus is an interesting subject for astrobiological study. Astrobiological studies on Venus would focus on four questions: searches for past life; studies of present chemistry, atmospheric evolution and climate; investigating the possibility of present-day atmospheric life; and studying the possibility of future life.

3. Astrobiology on Venus

3.1 Past Life

If early Venus in fact had a temperate climate and an ocean, could life have evolved on Venus? This question will be extraordinarily difficult to answer for a number of reasons. Even on the surface of the Earth, four-billion year old fossil life is difficult to find and difficult to unambiguously identify once found. The environment of Venus is more hostile than that of Earth, and the planetary exterior is resurfaced by volcanism more recently than that of Earth. However, finding and studying fossils of early Venus life, if it ever existed, would be of great interest to astrobiology.

3.2 Chemistry and Evolution of Atmospheres

Studying Venus is also significant toward understanding the chemistry of atmospheres and the evolution of terrestrial planet atmospheric chemistry, allowing us to begin to understand how planetary conditions and chemistry change from the formation of the planet to the present day. Understanding the atmosphere of Venus is important to learning about and understanding the climate and atmosphere of Venus and the Earth. It is also of significant interest to astrobiology, in order to elucidate by what mechanisms the climate of a planet will stay within the habitable “liquid water” zone, whether such planets are common or uncommon in the universe, and whether the chemical evolution of atmospheres and carbon compounds is a likely or unlikely process. If we are to search for chemical signatures of the possible building blocks of biology and the current existence of life in other solar systems, it will be necessary to first understand the variety of chemistry possible in the Earthlike planets in our own solar system, and to understand which chemical processes are unambiguous signs of life, and which can be produced by abiological means.

In addition, Venus is the best laboratory in the Solar system for study of the greenhouse effect. If we are to understand climate change on Earth, we can learn by comparing and contrasting the history and climate of the Earth with that of its nearby neighbors, Venus and Mars. A measurement of infrared absorption, reflection, and emission in the atmosphere of Venus will do much toward elucidating the greenhouse effect mechanisms on Venus, and allowing us to compare and contrast the greenhouse effect on Venus with that of Mars and Earth, and understand the effect of life and the impact of human actions on the environment

3.3 Present Life

Could bacterial life exist in the atmosphere of Venus today? Although this is considered unlikely, the possibility of life in the clouds or the middle atmosphere of Venus has not been ruled out by any observations made to date. While the atmosphere is both dry and acidic, extremophilic life has adapted to far more harsh conditions on Earth.

There is some evidence that the trace-gas constituents of the Venus atmosphere are not in chemical equilibrium with each other. On Earth, the primary source of disequilibrium in the atmospheric chemistry is the activities of biological processing; could disequilibrium on Venus also be a sign of life? In 1997, David Grinspoon made the suggestion that microbes in the clouds and middle atmosphere [4] could be the source of the disequilibrium. In 2002, Dirk Schulze-Makuch [6] independently proposed that observations of the Venus atmosphere by space probes showed signatures of possible biological activity.

As noted by Grinspoon and Schulze-Makuch, the Venus atmosphere has several trace gasses which are not in chemical equilibrium. The Venera missions and the Pioneer Venus and Magellan probes found that carbon monoxide is scarce in the planet's atmosphere, although solar radiation and lightning should produce it abundantly from carbon dioxide. Hydrogen sulfide and sulfur dioxide, two gases which react with each other and thus should not be found together, are also both present, indicating some process (possibly biological?) is producing them. Finally, although carbonyl sulfide is difficult to produce inorganically, it is present in the Venusian atmosphere. On Earth, this gas would be considered an unambiguous indicator of biological activity. While none of these chemical combinations are in themselves an unambiguous sign of life, it is interesting enough to warrant a more careful look at the atmospheric chemistry.

Another interesting sign is the nature of the ultraviolet-absorbing aerosols that form the markings seen in UV images of the planet (figure 2). The nature of these aerosols, and whether they are biological in origin, is still unknown.

On Earth, viable microorganisms are found in clouds. A research team from the University of Innsbruck examined bacteria from cloud samples by freezing onto Teflon plates water droplets collected in-situ from cloud samples from Mount Sonnblick. They then melted the samples in the laboratory and monitoring bacterial growth at the low temperatures found in clouds [7]. On the average, the cloud droplets contained around 1500 bacteria per milliliter, including round, rod-shaped and filamentary shaped bacteria, actively metabolizing at the cloud temperatures. Because the bacteria multiply over a time scale of several days, shorter than the typical lifetime of a cloud, they concluded that the bacteria collected "almost certainly reproduced inside the cloud." Cloud temperatures on Venus are similar to the range of cloud temperatures on Earth, although the Venus clouds are strongly acidic in composition. Nevertheless, identification of cloud-dwelling bacteria on Earth is a strong supporting evidence for the plausibility of bacterial life in the atmosphere of Venus.

Most of the primary materials required for life are present in easily accessible volatile form in the atmosphere of Venus. Almost 97% of the mass of living organisms (over 99.9% by atomic percentage) consists of the four elements: hydrogen, oxygen, carbon, and nitrogen; about 98% of the mass consists of these four plus sulfur and phosphorus. Of these, hydrogen, oxygen, carbon, nitrogen, and sulfur are present in significant amounts in the atmosphere. Sulfur is both a component of amino acids, and also an electron donor/acceptor anion used for respiration by some anaerobic bacteria in environments where free oxygen is not abundant; this may be a metabolic pathway that is plausible for the sulfur-rich Venus atmosphere.

The limiting resource for Venus atmospheric life would thus most likely be the requirement for phosphorus. Phosphorus is not a major constituent of the Venus atmosphere, although it is present [8]. Required cations such as calcium, potassium and sodium would also be likely to be limiting resources, along with trace mineral requirements such as magnesium and iron. It is plausible that some amount of these minerals will be present either from aeolian dust, or from volcanic sources, but these have not yet been detected in the Venus atmosphere.

Finally, the study of astrobiology has primarily been focused on life in the liquid-water phases. This is a reasonable focus, since all known life on Earth is based on carbon compounds with a liquid water medium, however, it is worth keeping in mind that other possibilities for biological chemistry may exist of which we are as yet unaware [4].

3.4 Future Life

As the most hospitable location in the solar system, other than Earth, the environment of Venus is worth considering as a possible future location of humans. The NASA vision, according to administrator O’Keefe, is to “Improve life here, extend life to there, and find life beyond.” The possibility of terraforming Venus, first proposed by Sagan in 1961 [9], has attracted a large amount of public attention. Unfortunately, later studies [4,10,11] show that the concept of converting Venus into an Earthlike environment is a far more difficult problem than initially considered. In 1994, Sagan conceded that his concept for terraforming Venus with atmospheric microbes, then three decades old, was naïve:

“Here’s the fatal flaw: In 1961, I thought the atmospheric pressure at the surface of Venus was a few bars ... We now know it to be 90 bars, so if the scheme worked, the result would be a surface buried in hundreds of meters of fine graphite, and an atmosphere made of 65 bars of almost pure molecular oxygen. Whether we would first implode under the atmospheric pressure or spontaneously burst into flames in all that oxygen is open to question. However, long before so much oxygen could build up, the graphite would spontaneously burn back into CO₂, short-circuiting the process.” [12].

While terraforming of Venus will not be as simple as originally suggested, it nevertheless may be possible to develop technologies to terraform the planet to habitable conditions. Possible methods of terraforming Venus are reviewed in detail by Fogg [11].

Even if Venus is not terraformed to a degree suitable for human occupation on the surface, Venus could potentially be a habitat for life bio-engineered by humans. Carl Sagan suggested that plants engineered by humans to incorporate hydrogen gas bladders could float amid the more hospitable cloud layers. In fact, hydrogen is unnecessary: even oxygen or nitrogen bladders would allow lightweight plants float in the carbon dioxide atmosphere. Kelp, for example, is a common ocean plant that uses atmosphere-filled bladders to float in the ocean (figure 3); on Venus, the same gas would be lighter than the carbon-dioxide atmosphere. While Venus may not be home to life in the present day, it may yet, in the future, have a human-engineered atmospheric ecosystem.

Finally, even if humans cannot terraform the surface of Venus, it will still be possible for humans to visit and live in aerostats in the atmosphere of Venus [13].

4. Venus: Spacecraft Missions

While exploration of Venus has attracted less attention than Mars exploration, a number of missions have examined our sister planet. The Russian “Venera” missions landed probes on the surface and looked down on Venus from orbit, and the “Vega” mission floated balloons into the clouds of Venus. The American Pioneer missions looked at Venus with orbiters and atmospheric probes, while Magellan imaged the topography of the surface of Venus with radar.

Japan plans to launch its first robotic mission to Venus in 2007, with the spacecraft expected to start orbiting the planet in 2009. The European Space Agency plans to launch the “Venus Express” mission, a near-duplicate of their 2003 Mars Express mission, is planned for a launch in late 2005 and arrival in 2006.

There are currently no NASA missions scheduled to revisit the planet Venus, but this might change. Several interesting Venus missions have been recently proposed, including balloon and aircraft explorations of the atmosphere of Venus [14], and sample-return missions from the surface.

5. Conclusion

Our sister planet, Venus, is both similar and different from the Earth, but despite differences, it is still the most earthlike of all the environments in the solar system. There is a strong case for studying astrobiology on Venus, to search for possible past life on the surface, for presently existing life in the atmosphere, to study the chemical evolution and environment of an Earthlike planet, and to speculate on the possible future of Venus as a habitat for humans.

Regardless of whether life is, or has been, present on the surface or in the atmosphere of Venus, we will learn about the atmosphere, climate, and ecosystem of the Earth by studying Venus.

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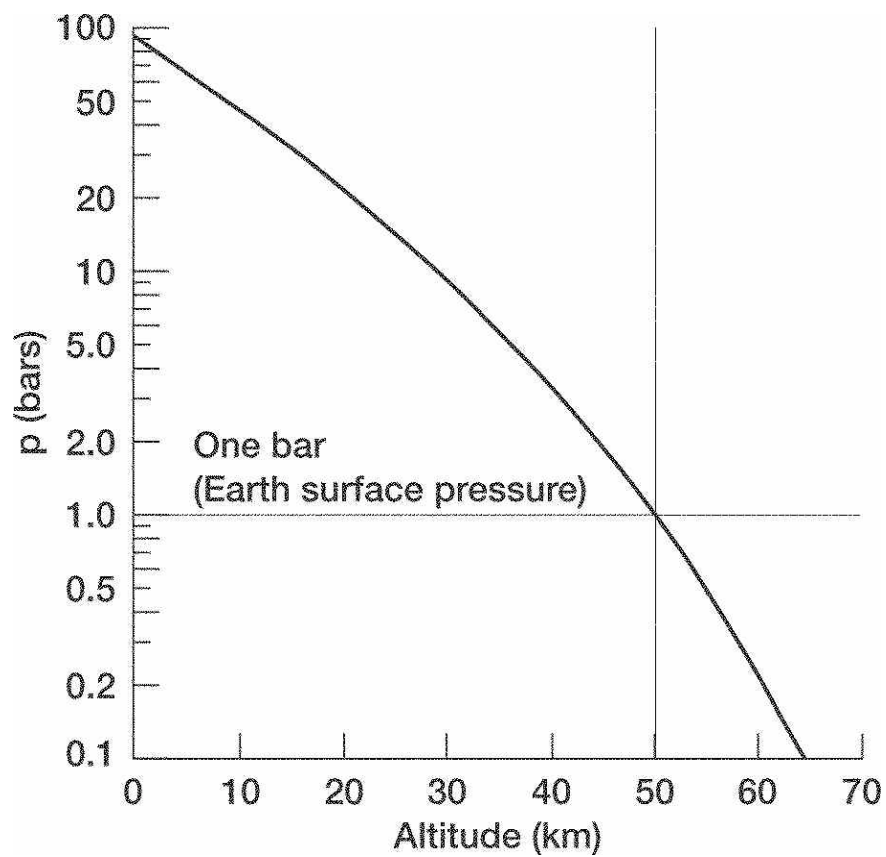


Figure 1: Atmospheric pressure as a function of altitude on the planet Venus, with the atmospheric pressure at the surface of the Earth, one bar, indicated.

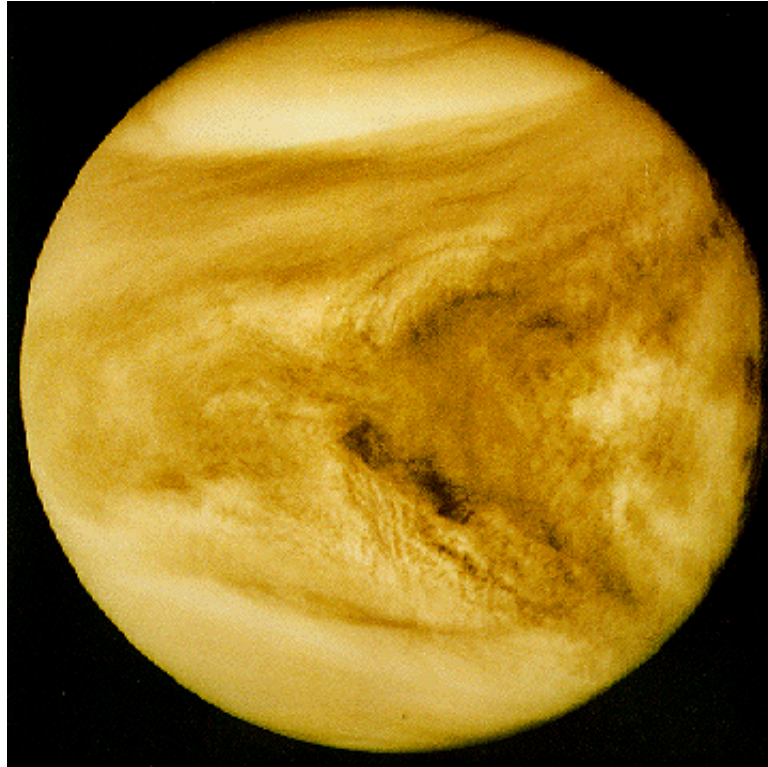


Figure 2: Venus viewed in the ultraviolet from the Pioneer spacecraft.
The identity of the dark ultraviolet-absorbing aerosols forming the
markings visible in the atmosphere is still unknown.



Figure 3: Kelp air bladder. The bladder gives kelp the buoyancy to float in the ocean. On Venus, the gas filling these bladders would be less dense than the carbon dioxide atmosphere (photo courtesy of Paul Kemp; used with permission).

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